

Usability and utility of the SnipTouch innovative agility training device prototype in patients with upper extremity impairments after stroke: a multiple case study

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Abstract. Research focus and aim: To investigate the usability and utility of the *SnipTouch* innovative agility training device prototype in patients with upper extremity impairments after stroke. Research methods used: The study of several case studies was selected by formulating the research phenomenon and proposing two units of analysis- 1) usability and 2) utility of innovative prototype device *SnipTouch*. The multiple case study involved 7 stroke survivors with impaired upper limb functions who participated in eight physiotherapy sessions adding the *SnipTouch* intervention. The device operates on a dexterity training principle, where the main task is to quickly touch a lit button. Participants underwent pre-intervention upper extremity assessments using ROM, MMT, NRS, MAS, FMA-UE, 9HPT, BBT, and RTT. After the eighth session of physical therapy, reassessments were conducted with the same tools, supplemented by semi-structured interviews and usability evaluations using UEQ and SUS. The collected data were compiled and analysed using established data analysis methods. Results: Five participants assessed the usability of the equipment in the SUS questionnaire as outstanding (from 87,5 to 97,5 points), one participant as excellent (82,5 points) and one very good (77,5 points). The UEQ on six scales resulted in the following device evaluation: attractiveness 2.6, perspicuity 2.79, efficiency 2.32, dependability 2.14, stimulation 2.64, novelty 2.43. The UEQ benchmark classifies the innovative prototype device *SnipTouch* into *Excellent* category. The results of the upper limb functional tests show improvements in all participants. The main Conclusions and Recommendations: The results of the study demonstrate that the *SnipTouch* innovative device prototype is usable and the overlap of qualitative and quantitative data confirmed the utility of the device in improving reaction time, range of motion, agility, movement coordination, muscle strength, in addition to conventional rehabilitation therapy methods for stroke patients.

Keywords: agility training in stroke patients, innovative device prototype, usability, utility

I. INTRODUCTION

Stroke, the third leading cause of death and the main contributor to global disability, has seen a decrease in mortality in recent years, resulting in a growing population of survivors [1]–[3]. Despite this, up to 80% of patients experience functional impairments and limitations in the upper extremities during the acute phase after a stroke, and 33-66% of patients cannot achieve full functional recovery of the upper extremities in 6 months [4], [5]. Timely rehabilitation is crucial to minimize long-term functional impairments [5]. Research highlights the effectiveness of high repetition upper extremity movements for stroke recovery, highlighting the importance of intensity and duration of continuous therapy [6], [7]. Innovative technologies, including agility training devices, present opportunities to create engaging rehabilitation environments, improve patient motivation, and provide necessary repetitions with minimal supervision [8]–[10]. Despite the available methods, a significant number of stroke survivors continue to face long-term impairments of the upper limb, which requires the exploration of new approaches, particularly those focused on agility [11], [12]. The "SnipTouch" agility training device was developed as a prototype with the aim of enhancing users' agility and improving various motor skills. Although agility training devices have shown promise in improving physical and cognitive skills, more research is needed on their usability and efficiency, especially in stroke patients with upper extremity impairments [13]. To address this gap, our research aims to investigate the usability and utility of the SnipTouch innovative agility training device prototype in patients with upper extremity impairments after stroke.

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II. MATERIALS AND METHODS

Study Design

Based on the research objective, a multiple case study analysis was chosen as the study design. Following the methodology of Yin [14], the phenomenon under investigation was initially formulated as “usability and utility of the SnipTouch innovative agility training device prototype in patients with upper extremity impairments after stroke”. Given that the phenomenon could be divided into separate parts, the fourth type of analysis design was utilized [14]. The study analysis units were formulated as: 1) the usability of the "SnipTouch" innovative device prototype; 2) the utility of the "SnipTouch" innovative device prototype.

Prototype Development and Assessment Process

Based on the information obtained on medical device standards, the research author developed the "SnipTouch" prototype from October 4, 2021, to January 31, 2022. The primary objective in developing the prototype was to provide a rehabilitation device that excels in usability and applicability, is easy to understand, learn, and setup. The design focused on creating a practical and versatile tool that can be adapted to various rehabilitation goals in various patients, focusing on ease of use and broad applicability without compromising quality or increasing costs. At this stage, the development included programming the Arduino Nano microcontroller using the Arduino Integrated Development Environment (IDE) 1.8 with C++ as the programming language. Currently, the device was designed using 3D modelling software, followed by the fabrication of its components using 3D printing techniques. Subsequently, all hardware components were assembled to complete the device. In addition, a biomedical engineer was appointed to verify the device's compliance with applicable safety standards.

Participant Selection Criteria in the Multiple Case Study

The selection of study participants for the multiple case study was performed based on the research selection criteria, combining convenience and purposeful sampling to ensure the inclusion of theoretically distinct cases. Within the context of a single case, one patient being treated in the Neurorehabilitation Department of NRC “Vaivari” during the study was included. The study included patients who agreed to participate and met the initial selection criteria: 1) Men and women at least 18 years old after a first ischemic or hemorrhagic stroke on either the right or left side, confirmed by magnetic resonance imaging or computed tomography; 2) The expected treatment duration at NRC “Vaivari” is no less than 10 working days; 3) No pronounced cognitive impairments, capable of adequately cooperating with the rehabilitation team, a Mini-Mental State Examination (MMSE) [15] score of 16-30 points; 4) No pre-stroke conditions affecting upper extremity functions; 5) No dislocations or subluxations in the upper extremity identified in the patient's medical history through radiology; 6) Upper extremity paretic function impairment(s), not achieving the maximum score of 18 points in sections six, seven, and eight of the Motor Assessment Scale (Upper Limb Function, Hand

Movements, Advanced Hand Movements) [16], with at least two points in section six; 7) Able to communicate and read in Latvian; 8) None of the following exclusion criteria apply: a) pain in any joint of the paretic upper limb more than 5 points according to the NRS; b) spasticity in any muscle of the paretic upper limb more than 2 points according to the Ashworth scale; c) motor aphasia; d) diagnosed epilepsy.

Intervention and Implementation of the “SnipTouch” Prototype

Before starting the intervention, the upper extremity functions of the participants were evaluated using evaluation tools: Range of Motion (ROM) assessment (goniometry) [17], Manual Muscle Strength Tests (MMT) [18], pain assessment using the Numerical Analog (rating) Scale (NAS) [19], Modified Ashworth Scale (MAS) [20], Fugl-Meyer Assessment for Upper Extremity (FMA-UE) [21], Nine Hole Peg Test (NHPT) [22], Box and Block Test (BBT) [23], Reaction Time Test (RTT) [24]–[26]. Evaluation conducted by an independent researcher. To start the intervention with “SnipTouch”, all the physiotherapists of the study participants received instructions for using the innovative "SnipTouch" device prototype, in addition to the individual practical training sessions on the application were conducted because the intervention was performed by the physiotherapist. During eight physiotherapy sessions (60 min), the physiotherapists, in addition to conventional physiotherapy methods, conducted training using the innovative “SnipTouch” device prototype for the study participant. The operating principle of this device is classified as an agility training equipment type. To use the device, its components are affixed to surfaces chosen by the user. The placement of the button, the size, and the speed of operation of the device vary according to the user's needs and abilities of the user. The primary task of the user is to touch the lit button as quickly as possible (see Fig. 1. and Fig. 2.). Upon touching the lit button, the next one lights up, and the interval between the lighting of the buttons automatically decreases, facilitating an increase in the user's reaction speed and movement speed for successful task completion. The device provides feedback evaluation or indicates the results obtained. During the use of the device, the user performs movements with a high repetition rate. The device consists of five multicolored buttons in two size variations (small with a diameter of 5 mm and/or large with a diameter of 3.5 cm) and a control unit. In addition, there are connection wires of various lengths and device mounts for different surfaces. Based on established rehabilitation goals and the needs of the participant's physiotherapist, the duration of the intervention, the size and placement of the buttons, and the operating speed were selected. The participant underwent a re-assessment of upper extremity functions using the previously applied evaluation tools, and a semi-structured interview was conducted. Study participants were asked questions about the suitability for their needs and rehabilitation goals, as well as the usability of the device and the usefulness of its use to improve upper extremity function. The usability of the device was evaluated using the User Experience Questionnaire (UEQ) [27] and the System Usability Scale (SUS) questionnaire [28], [29].

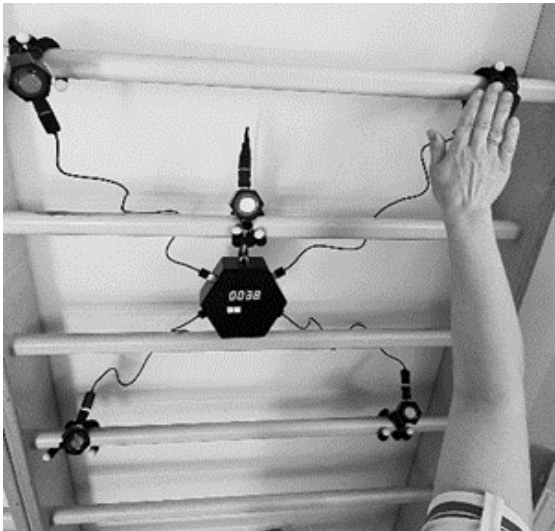


Fig.1. The participant performs a task by pressing the large 3.5 cm buttons on the SnipTouch device prototype mounted on a Swedish wall.



Fig. 2. Participant performs a task by pressing the small 0.5 cm buttons on the SnipTouch device prototype with a dowel.

Data Analysis Methods

In the study used an inductive analysis strategy [14]. Qualitative data were transcribed and coded into categories and subcategories by inductive content analysis with deductive elements. Data were organized by analysis units, identifying patterns, similarities, and differences between and within cases, integrating findings to understand larger correlations. For Range of Motion (ROM), Manual Muscle Strength Tests (MMT), the Numerical Analog (rating) Scale (NAS), Modified Ashworth Scale (MAS), Fugl-Meyer Assessment for Upper Extremity (FMA-UE), Nine Hole Peg Test (NHPT), Box and Block Test (BBT), Reaction Time Test (RTT) scores, and usability scales, descriptive statical methods were used.

F.Ethical Considerations

The study was conducted in accordance with the Declaration of Helsinki [30]. The study adhered to ethical standards according to the Declaration of Helsinki and European data protection regulations, with approval from the ethics committees of Rigas Stradins University (decision no.22-2/559/2021) and NRC "Vaivari" (Nr.40, decision no.4.1).

III. RESULTS AND DISCUSSION

The study consisted of seven participants, creating seven cases for analysis. All participants completed the study with complete data, allowing them to be included in the analysis. The details are in Table I.

The first unit of analysis - Usability

Summarising the results of the SUS questionnaire, it was determined that five participants (P1, P2, P4, P5, P7) rated the device's usability as excellent, corresponding to an A+ level. Expressing the A+ assessment in points, it ranged from 87.5 points for participant P6 to 97.5 points for participant P7. Participant P3 scored 82.5 points on the questionnaire, corresponding to an excellent device usability rating of A. Meanwhile, participant P4 indicated a B+ rating or very good usability of the device. According to the methodology guidelines, the results of the UEQ must be expressed for the entire sample as an average score assessment. Therefore, the following results were obtained on the six UEQ scales. Study participants rated the attractiveness of the device with an average of 2.6 points, perspicuity with 2.79 points, efficiency with 2.32 points, dependability with 2.14 points, stimulation with 2.64 points, and novelty with 2.43 points (see Fig. 3.). The UEQ benchmark classifies the innovative prototype device "SnipTouch" into "Excellent" category. In the proportional distribution of the responses for the 26 items of the UEQ scale, it was found that most of the participants rated the device as friendly, attractive, practical, clear, useful, and meeting expectations, motivating, safe, good, easy to use, valuable, easy to learn, understandable, modern, pleasant, and supportive. Most of the participants evaluated the device as innovative, original, creative, interesting, enticing, and exciting, but one participant P1 rated it as average between innovative and conservative, average between original and widely accepted, rated it as average between creative and monotonous, average between interesting and uninteresting, average between enticing and repelling, average between exciting and boring. Six participants indicated that the device is organised, but participant P2 indicated that the device is partly poorly organised. Most of the participants evaluated the device as average between fast and slow, but three participants, P2, P5, and P6, rated the device as fast. Three participants (P4, P5, P6) rated the device as predictable, participant P1 rated the device as average between predictable and unpredictable, while P2 rated it as partly predictable and participants P3 and P7 rated the device as very unpredictable.

TABLE I

	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6	Case 7
Subsequent notation in the paper	P1	P2	P3	P4	P5	P6	P7
Age	47	53	48	57	69	61	60
Sex	Female	Male	Female	Female	Male	Male	Male
Stroke type	Ischemic	Hemorrhagic	Ischemic	Hemorrhagic	Ischemic	Hemorrhagic	Ischemic
Location of brain damage	ACM dxt.	ICH sin. frontal lobe	ACM dxt.	ICH sin. frontal lobe	ACM dxt.	At the Pons	ACM sin.
Time after stroke	66 days	159 days	89 days	152 days	120 days	89 days	145 days
Paretic side	Left	Right	Left	Right	Left	Left	Right
Dominant hand	Right	Right	Right	Right	Right	Right	Right
Total score on the Motor Assessment Scale (sections 6-8)	15	12	12	8	15	9	10

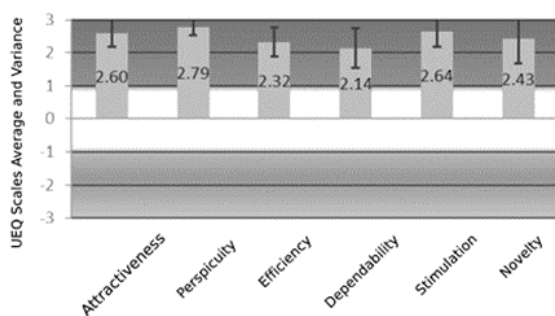


Fig.3. The UEQ scales the main parts scores average and variance.

Data obtained from participants in interviews related to Usability: Evaluation of the Session Process: The participants noted that using the device was interesting and exciting and that they were satisfied with their experience using the "SnipTouch" device prototype. The data from the interview were collected, coded, and separated into 6 categories: 1. *Difficulty Level of Using the Device*: Initially, three participants found the device and the tasks easy to understand, while four adjusted after the first use. Some found it easier with time or with improved physical ability. Challenges included variable button placements, operating speed, performing tasks accurately, using a stylus for small buttons, and visibility issues for a participant with hemianopsia, making task execution more complex for some. 2. *Well-being During Device Use*: Participants reported positive feelings, high motivation, and satisfaction with their achievements. Some experienced emotional relief, despite challenges such as numb fingers or discomfort in the paretic limb, leading to the need for rest breaks. An increase in self-confidence was observed as the familiarity with the device grew. 3. *Well-being After the Device Use Session*: After use, participants experienced positive results, including pleasant fatigue in the paretic limb for some, emotional uplifting for others, and general good sense of well-being, indicating beneficial effects of the session. 4. *Strengths of the Device*: Key strengths identified include ease of use, the ability to monitor results, creative design, engaging and interesting use process, and colourful buttons. Furthermore, its use was noted to distract from pain, enhancing the appeal of the device. 5. *Drawbacks of the Device*: Identified flaws include unstable button

attachments and USB connections, insufficient brightness of large buttons, and too small button sizes, pointing to areas for potential improvement in design and functionality. 6. *Future Perspectives on Using the Device*: Most of the participants are interested in future use and one is ready to buy it. There is a consensus on its potential to speed up rehabilitation goals and the desire for a wider availability. Although some see no need for changes, others suggest improvements such as better button attachments and brighter large buttons to enhance usability and effectiveness.

The second unit of analysis - Utility

Data obtained from Participants' Functional Test Results:

Range of Motion: All participants exhibited improvements in upper limb mobility, excluding shoulder adduction, already at normal levels. However, P4 experienced a slight decrease in shoulder abduction (active: 98 to 85 degrees, passive: 136 to 126 degrees). P2 observed reductions in active pronation (67 to 54 degrees) and active extension (40 to 30 degrees), passive extension also decreased (66 to 53 degrees) and reported notable pain.

Muscle Strength: Assessed at up to three points for P2, P4 and P7 due to increased tone, all participants experienced improvements in muscle strength, with the most significant gains in P2 and P6 in eight muscle groups.

Muscle Tone: Four participants started with normal tone; P2 and P7 experienced reduced spasticity in some muscles, while P4 observed a slight increase in muscle tone in the m. flexor digitorum, increasing from 1 to 1+ on the Ashworth scale.

Pain Intensity: P2 experienced an increase in wrist pain, going from a score of 4 to 5. On the contrary, P4 saw a decrease in pain levels from 5 to 2, and P7 from 5 to 3. P1's pain, initially rated at 5, disappeared entirely, similarly to P6, whose shoulder pain went from 3 to non-existent. The pain level and character of P3 and P5 remained unchanged, consistently with a score of 5, primarily due to positioning.

FMA-UE: During their therapy, six participants showed improvements in the Fugl-Meyer Assessment for

Upper Extremity scores across Domains A to D, with the exception of P2, whose overall score remained unchanged. P3 experienced the most significant improvement, with their score increasing from 45 to 61 points, especially noted in the Coordination/Speed and Upper Extremity domains. P1 reached the maximum possible score of 66 points, with an improvement of three points. All participants improved in at least one domain, except P1 and P5, who began with maximum scores in the Hand domain, and P2, who did not observe any change in Coordination/Speed, remaining at 2 points, and experienced a decrease in the Hand domain score from 13 to 10 points.

NHPT: The test showed that all participants tested improved in the second assessment, with P3 having the most significant improvement of 37.8% and P1 the smallest at 2 seconds, indicating initial results within the normal range.

BBT: The test results showed improvements for six of the study participants (P1, P2, P3, P4, P6, P7) between the initial and second evaluations. The increases ranged from a minimum of 2 blocks (P2) to a maximum of 9 blocks (P7). In contrast, P5 did not show any performance change, maintaining a score of 23 blocks in both assessments.

RTT: The average results of the reaction time test indicated that all study participants had a positive trend in reaction time changes. Participant P4 experienced the largest change, with a 21.3% improvement, which was the most significant change among all participants, while the smallest changes were observed in participant P2, whose result changed by 0.6%.

Data obtained from participants in interviews related to Utility:

In interviews, participants reported that using the "SnipTouch" device prototype was beneficial, noting improvements in 13 physical aspects, two psychoemotional and two cognitive areas from its use. They experienced enhanced movement range, coordination, and speed of movement in their paretic upper extremities. Specifically, improvements in fine motor skills (P1, P2, P7), daily activity use (P4, P5), reduced intensity of pain (P3, P6), better self-care and dexterity (P2), increased muscle strength and decreased tremor (P4) were observed. Enhanced sensation (P6) and better grip (P7) in the paretic upper extremity were also reported. Participants noted better reaction times, attention skills, and increased self-confidence, with three mentioning increased self-esteem after device use. P3 experienced an improvement in mood. Motivation to achieve greater achievement led to faster task completion and, for some, greater self-confidence. The ability to press buttons with a stylus improved self-confidence (P2, P7) and encouraged the use of the paretic limb for writing. The use prompted a more effective use of the paretic upper limb for tasks (P4, P7) and required coordinated movement and precision (P3, P5, P7), with the placement encouraging full use (P7) and improving the range of active motion (P4).

In analyzing user feedback on the "SnipTouch" prototype five participants rated the usability of the device

as excellent in the SUS questionnaire, while two participants rated it as good. These results suggest that these users would likely recommend the "SnipTouch" prototype for use by others. Although one participant rated the device's usability as very good, their completed questionnaire revealed a need for technical assistance from another person to set up and select the device's operating speed, indicating a complexity in use. The participant also mentioned the excessive learning required. The information shared during the interviews clarified these results, highlighting the initial difficulties in understanding how to use the device. According to Liu [31], patients with lower functional and cognitive abilities might require a longer period to process new information. Three participants found it easy to understand how to use the device, its operating principles, and the essence of the tasks right from the start, while the rest grasped how to use the device only after their first experience or trial. Hugues [32] noted that individual's post-stroke individual may need more time and practical trials to learn a new skill. During the interviews, the patients expressed great satisfaction with the use of the device during sessions, which was attributed to the ease of use and the engaging and interesting process. Patients emphasised their high motivation to complete tasks during sessions, consistent with Thomson [33] who found that game-formatted tasks motivate patient participation. Three study participants mentioned that the ability to track the results was a strong aspect of the device, encouraging more active participation. The patients also highlighted those bright lights created emotional uplift. Chen [33] emphasized the importance of participating in the rehabilitation process to increase patient participation, potentially enhancing rehabilitation benefits. Wang [35] suggested that including game elements requires a balance between challenge and avoiding loss in games. This explains the observations in the current study, in which a participant showed low interest and motivation after setting the device at a speed faster than the participant could manage. Reducing the speed in the next session improved the participant's ability to complete tasks and increased their desire to continue using the device. Variability in button placement and device speed during sessions added diversity, which is essential to maintain high patient interest and motivation. This finding is supported by Wang [34]. However, patients who had difficulty holding the peg and pressing small buttons of the device found it challenging. Research confirms that people after stroke experience difficulties with fine motor and grasping, significantly impacting daily activities [36], [37]. Basteris [38] highlighted the need for a high number of repetitions to improve skills. In this study, the patient's ability to press small buttons improved with extensive practice of fine motor skills and grasping during sessions. In interviews, participants identified unstable button attachments to surfaces as a primary drawback of the device, echoing findings from Myers [39] regarding the FitLight device. This suggests the need for improved button attachments for the "SnipTouch" device, considering the deep sensation, movement coordination, and precision difficulties of patients. Future iterations of the "SnipTouch" should consider wireless technology to avoid wire interference in task performance. The agility training devices currently available are primarily designed

for functionally independent individuals, such as athletes. For example, BlazePod and FitLight devices are very advanced, including wireless multicolored LED buttons, which are controlled using an Android or iOS application. In contrast, the initial design concept of SnipTouch device was intended to be maximally easy to use, understandable, and adaptable for any user and their needs, financially inexpensive, and controllable without additional devices (without phone applications) [40], [41], [42]. Using the FitLight system, Al-Selmi and Hosen [40] observed significant improvements in aerobic capacity, speed, and hit quality in badminton players after eight weeks of training. Rogozhnikov [41] reported a 36.2% improvement in task execution time in basketball training with FitLight over four weeks. Chepanov [42] found significant enhancements in reaction speeds and emotional states in karate training with BlazePod devices among teenagers. Such observations indicate that such agility training devices have great potential to improve agility, movement speed, reaction speed, and other physical and functional abilities. Upon analysing information from interviews and data from functional tests, an examination of overlapping data was conducted. This data overlap was interpreted as an indication of the device's utility. Data overlaps confirmed the utility of using the device to improve reaction speed, movement speed, grip, range of motion, fine motor skills, coordination of movements, and muscle strength when applied in addition to conventional rehabilitation therapy methods. This research encountered several limitations that warrant consideration when interpreting the findings. Firstly, the study was characterized by a relatively small sample size, which may impact the generalizability of the results. Additionally, the homogeneity of the study group, which comprised only post-stroke patients with similar functional disorders and their origins, suggests that the utility of the "SnipTouch" prototype might not fully extend to other populations with impaired upper limb function. This underscores the importance of expanding future research to include a more diverse range of participants to validate the prototype's usability and utility more broadly. A significant factor to consider is that all participants were recruited from a single rehabilitation centre. This uniformity in the rehabilitation setting, characterized by a particular treatment environment and methodology, as well as concurrent exposure to various therapeutic interventions, could have influenced the study results. The observed effects observed may, in part, be attributable to the comprehensive rehabilitation approach at the center, rather than the "SnipTouch" intervention alone. Another critical consideration is the varied participants individual factors affecting usability and utility assessments. These variations include attitudes toward new technologies, prior experiences with such technologies, and the influence of personal life philosophies, cultural backgrounds, and social contexts. These factors highlight the complexity of evaluating new rehabilitation interventions and underscore the importance of considering a broad spectrum of individual differences in future research. Additionally, the researcher's dual role as both the inventor of the device and the interviewer in participant interactions could have influenced responses. To ensure credibility, measures such as conducting open-ended interviews, separating personal views, and

verifying codes were implemented. However, there still remains the possibility that the researcher's involvement could have influenced participant responses and data interpretation. The findings of this study provide valuable insights into the usability and utility of the "SnipTouch" prototype, highlighting areas for further research and development in the field of rehabilitation interventions.

IV. CONCLUSIONS

A first multiple case study was conducted to explore the usability and utility of the "SnipTouch" device prototype during inpatient stroke rehabilitation. Integrated findings suggested that the "SnipTouch" technology was a feasible and acceptable tool for use in stroke patients participating in subacute inpatient rehabilitation. The participants reported high satisfaction due to its simplicity, understandability, and engaging nature, although technical properties such as mounting and fastening of the device were noted to need improvement. Furthermore, the results revealed the potential of the "SnipTouch" to enhance motor recovery of the upper extremity in stroke patients during inpatient rehabilitation. A "SnipTouch"-based approach appeared feasible and promising for post-stroke rehabilitation. A randomized controlled trial is recommended to further investigate efficacy.

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